Section 1
Introduction

This section provides background information about the SITE program, discusses the purpose of this ITER, and describes the CWS technology. Key contacts for additional information about the SITE program, this technology, and the demonstration site are listed at the end of this section.

1.1 Brief Description of the SITE Program and Reports

SARA mandates that EPA select, to the maximum extent practicable, remedial actions at Superfund sites that create permanent solutions (as opposed to land-based disposal) for contamination that affects human health and the environment. In response to this mandate, the SITE program was established by EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD). The SITE program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund sites across the country.

The SITE program's primary purpose is to maximize the use of alternatives in cleaning up hazardous waste sites by encouraging the development and demonstration of innovative treatment and monitoring technologies. It consists of the Demonstration Program, the Emerging Technology Program, the Monitoring and Measurement Technologies Program, and the Technology Transfer Program. These programs are discussed in more detail below.

The objective of the Demonstration Program is to develop reliable performance and cost data on innovative treatment technologies so that potential users may assess specific technologies. Technologies evaluated either are currently or will soon be available for remediation of Superfund sites. SITE demonstrations are conducted at hazardous waste sites under conditions that closely simulate full-scale remediation, thus assuring the usefulness and reliability of information collected. Data collected are used to assess the performance of the technology, the potential need for pre- and post-treatment processing of wastes, potential operating problems, and approximate costs. The demonstrations also allow evaluation of long-term risks and operating and maintenance (O&M) costs.

The Emerging Technology Program focuses on successfully proven, bench-scale technologies that are in an early stage of development involving pilot-scale or laboratory testing. Successful technologies are encouraged to advance to the Demonstration Program. The constructed wetlands is an example of a successful graduate of the Emerging Technology Program that was evaluated in the Demonstration Program.

Existing technologies that improve field monitoring and site characterization are identified in the Monitoring and Measurement Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Monitoring and Measurement Technologies Program also formulates the protocols and standard operating procedures for demonstrating methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Demonstration, Emerging Technology, and Monitoring and Measurement Technologies Programs through various activities. These activities increase the awareness and promote the use of innovative technologies for assessment and remediation of Superfund sites. The goal of technology transfer is to promote communication among remedial managers requiring up-to-date technical information.

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. ORD staff review the proposals, including any unsolicited proposals that may be submitted throughout the year, to determine which technologies show the most promise for use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stage, must be innovative, and must have some advantage over existing technologies. Mobile technologies are of particular interest. Once EPA has accepted a proposal, cooperative agreements between EPA and the technology developer establish responsibilities for conducting the demonstrations and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs for transportation, operation, and removal of equipment. EPA is responsible for project planning, site preparation, sampling and analysis, quality assurance and quality control (QA/QC), and for preparing reports, disseminating information, and transporting and disposing of untreated and treated waste material. For the CWS evaluation, CDPHE (the lead agency of the Burleigh Tunnel site) identified passive wetlands treatment as the preferred treatment alternative with agreement by EPA and the division of responsibilities was essentially as described.

The results of the CWS technology demonstration are published in two documents: the SITE technology capsule and the present ITER. The SITE technology capsule provides relevant information on the technology, emphasizing key features of the results of the SITE field demonstration. The ITER is discussed in the following section. Both the SITE technology capsule and the ITER are intended for use by remedial managers making a detailed evaluation of the technology for a specific site and waste.

1.2 Purpose of the Innovative Technology Evaluation Report

The ITER provides information on the CWS technology and includes a comprehensive description of the demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision makers for implementing specific remedial actions. The ITER is designed to aid decision makers in evaluating specific technologies for further consideration as an option in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology. To encourage the general use of demonstration technologies, EPA provides information regarding the applicability of each technology to specific sites and wastes. Therefore, the ITER includes information on cost and site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology. Each SITE demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics at other sites may differ from the characteristics of the treated waste. Therefore, successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.3 Technology Description

The Colorado Department of Public Health and Environment submitted a proposal to the SITE program for demonstrating the anaerobic compost CWS technology. This technology was selected for a SITE demonstration at the Burleigh Tunnel in Silver Plume, Colorado. The demonstration was carried out under a cooperative agreement involving the EPA National Risk Management Research Laboratory (NRMRL), CDPHE, and EPA Region 8.

The Burleigh Tunnel is located approximately 50 miles west of Denver in the Silver Plume - Georgetown mining district (Figure 1), within the Clear Creek/Central City Superfund site. The Silver Plume - Georgetown mining district occupies an area of about 25 square miles surrounding the towns of Silver Plume and Georgetown. The tunnel entrance is at an elevation of 9,152 feet, about 400 feet north of Clear Creek, on the western side of the town of Silver Plume. The area immediately surrounding the tunnel entrance is littered with mill tailings and waste rock dumps. Dilapidated buildings and equipment from previous milling operations are also present. No mining operations are active in the immediate area. The water draining from the Burleigh Tunnel is of near-neutral pH (ranging from 6.9 to 7.9) and has high zinc concentrations (ranging from 44.8 to 109 mg/L). The drainage also contains moderate alkalinity and low levels of metals other than zinc.

A treatability study was conducted at the Burleigh Tunnel between June 18, 1993 and August 12, 1993. The treatability study involved the construction, operation, and sampling of two upflow compost and hay bioreactors that treated mine drainage from the Burleigh Tunnel. The treatability study (PRC 1993) showed that low levels of sulfate in the mine drainage would not limit biological sulfate reduction, thereby permitting the removal of zinc and other metals by the bioreactors or the demonstration scale treatment cells. Construction of the CWS demonstration cells began in August 1993 and was

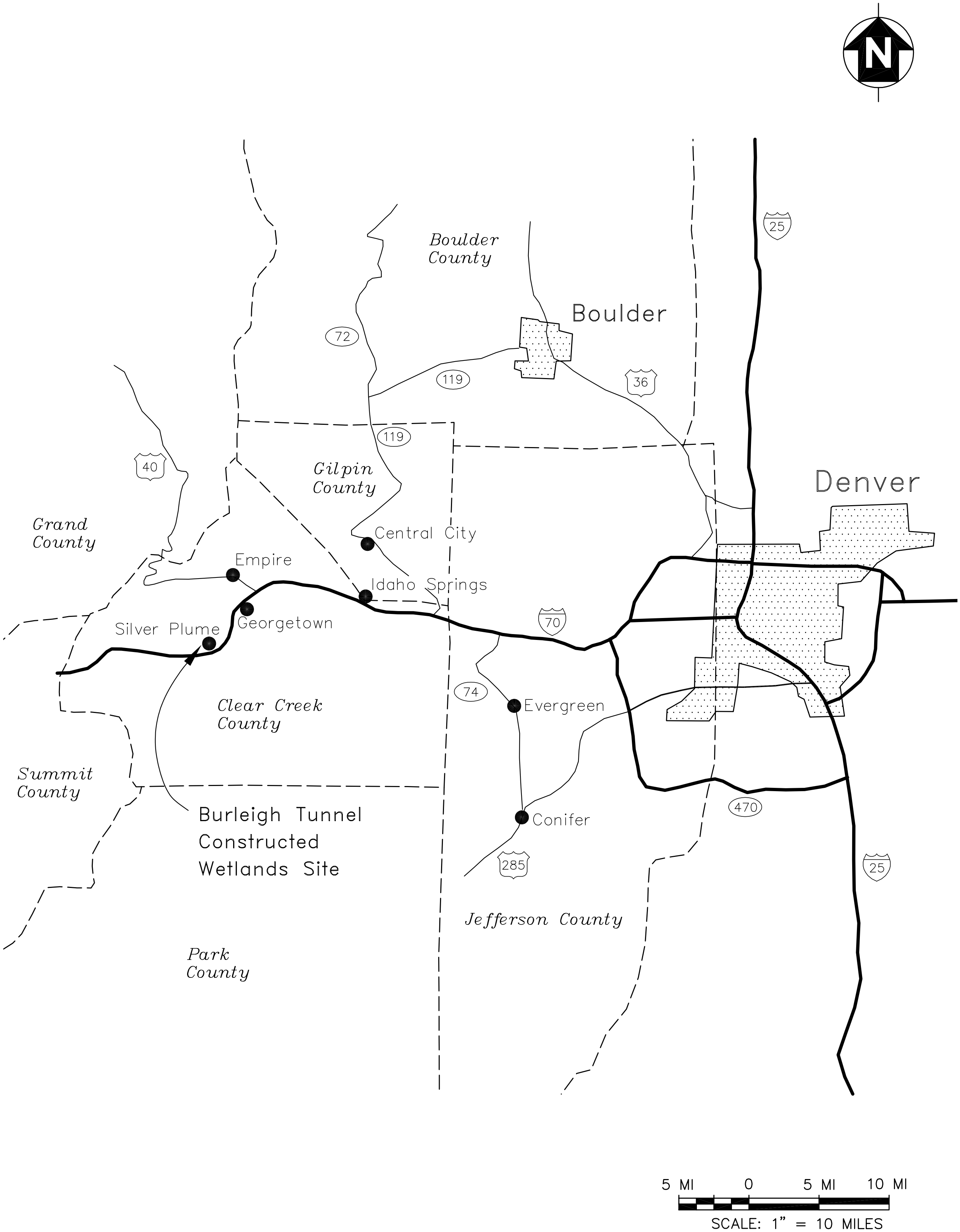

Figure 1. Site location.

completed in November 1993. The demonstration began in January 1994 and continued for a 46-month period through November 1997. Evaluation of the CWS technology is based on results of the treatability study and the SITE demonstration at the Burleigh Tunnel site.

1.3.1 Treatment Technology

There are generally three types of constructed wetlands: free-water surface systems, subsurface flow systems, and aquatic plant systems (EPA 1988). A free-water system typically consists of shallow basins or channels with slow- flowing water and plant life. A subsurface flow wetland consists of basins or channels filled with permeable substrate material; the water flows through, rather than over, this substrate. An aquatic plant system is essentially a free water surface system with deeper channels containing floating or suspended plants. In general, free-water surface and aquatic plant systems are aerobic wetlands that remove metals primarily by aerobic oxidation of iron followed by precipitation of iron hydroxides, that leads to the precipitation or adsorption of other metals. Aerobic wetlands are most successful in removing iron, arsenic, selenium and, to some extent, manganese from moderately low to neutral pH mine waters (Gusek and others 1994).

Anaerobic compost wetlands are designed to treat mine drainage through a combination of physical, chemical, and biological processes. Mine drainage is directed into constructed wetlands that contain an organic-rich compost substrate. Initially, sorption to the CWS substrate is the primary metal removal mechanism active within the system. Sorption includes adsorption of metals to organic and inorganic wetlands materials and absorption of metals into wetlands microorganisms and plants.

- Adsorption refers to the binding of positively charged ions to mineral surfaces by metal cations in solution. The sorption of inorganic ions is largely determined by complex chemical equilibria involving the charge and size of the element or complex ion, the nature of the sorbing material, and the pH of the aqueous solution. The properties of the surface that influence inorganic sorption include net surface charge and the presence, configuration, and pH dependence of binding sites. The structure of the solid may also affect adsorption reactions.

- Absorption refers to the incorporation of ions or compounds into the cell structure of microorganisms or plants. Metals may also be incorporated into the structure of complex humic substances formed during the degradation of the substrate.

After several months, the sorption capacity of the wetlands is exhausted and metal removal efficiencies by this mechanism decline.

Once the sorption capacity of the CWS substrate is expended, the formation, precipitation, and filtration of metal sulfides become the primary metal removal mechanism in the CWS. The process is believed to be biologically mediated by sulfate-reducing bacteria present in anaerobic zones within the CWS.

The bacteria oxidize organic matter provided by the wetland with the simultaneous reduction of sulfate to hydrogen sulfide. The hydrogen sulfide reacts with dissolved metals to produce metal sulfides. The metal sulfides, with low aqueous solubilities, precipitate and become trapped in the wetlands substrate by filtration. The following reactions illustrate the overall oxidation/ sulfate reduction reactions and subsequent formation of metal sulfides.

$$SO_4^{-2} + 2CH_2O \longrightarrow HS^- + 2HCO_3^- + H^+$$

$$M^{+2} + H_2S \text{ or } HS^- \longrightarrow MS(s) + 2H^+$$

where: M is a metal such as zinc (Zn^{+2}), iron (Fe^{+2}), nickel (Ni^{+2}), and (s) indicates a solid.

In addition, other reactions within the wetlands may contribute to observed metal removal, including mineral precipitation and chelation (binding) to suspended organic material. In general, mine drainage contains low levels of dissolved oxygen that, when exposed to air, will take up oxygen and become aerobic. This process can lead to geochemical disequilibrium where the metal is no longer soluble at this concentration and may initiate metal precipitation. Zinc carbonate (Smithsonite) is an example of a mineral that may precipitate in the demonstration downflow CWS. In addition, the decay of wetland compost and biomass will produce dissolved and suspended organic material in the wetland pore water. These materials can chelate metals in solution. Although chelated metals may not be effectively removed (filtered) by the wetland, they may not be available biochemically to aquatic plants and organisms exposed to the effluent.

1.3.2 System Components and Function

Two CWS treatment cells were located adjacent to the Burleigh Tunnel between a compressor building and an old mill. Each cell covered 0.05 acre; the two cells differed in flow configuration. The cell nearest the mine adit was an upflow system, in which water entered the cell under pressure from the bottom and flowed upward through the substrate material to discharge. The second cell was a downflow system, in which the water entered the cell from the top and flowed by gravity to the bottom for discharge. The demonstration CWS cells were highly engineered systems compared to many of the previously tested constructed wetlands, including the Big 5 wetlands evaluated in the Emerging Technology Program (EPA/540/R-93/523). Figure 2 shows a cross-section schematic of the upflow CWS treatment cell. The downflow cell was identical except the direction of mine drainage flow in the compost is reversed.

Both CWS treatment cells were installed below grade to reduce freezing of the cells during winter. Both had bermed earthen side walls. The base of each cell was made up of a gravel subgrade, a 16-ounce geofabric, a sand layer, a clay liner, and a high density polyethylene liner. The base was separated from the influent or effluent piping by a geonet. A 7-ounce geofabric separated the perforated PVC piping from the compost. The compost was held in place with a combination of 7-ounce geofabric and geogrid in the upflow cell. The perforated effluent piping was also supported by the geogrid in the upflow cell. Up to 6 inches of dry substrate material was located above the perforated piping. The geonet and the perforated piping ensured even distribution of the influent water into the treatment cells and prevented short circuiting of water through the cells. The influent and effluent distribution piping were also staggered horizontally as an additional precaution against short circuiting.

Existing construction near the Burleigh Tunnel entrance required that the upflow cell be 10 percent smaller by volume than the downflow cell. The dimensions of the cells are as follows:

- Upflow cell - 69 feet long, 25.5 feet wide, and 4 feet deep, with an estimated total substrate volume of 198 cubic yards
- Downflow cell - 62 feet long, 33 feet wide, and 4 feet deep, with an estimated total substrate volume at 218 cubic yards

Note: The dimensions listed are at the top of the cell wall. The volumes listed take into account the sloped walls of the cells.

The organic-rich compost substrate was composed of a mixture of 95 to 96 percent manure compost and 4 to 5 percent hay. The compost was produced from cattle manure and unidentified paper products. The compost and hay mixture had been identified as the most effective medium in removing zinc from the drainage during the previous bench-scale test (Camp, Dresser and McKee 1993). Wood based substrates have also been used in constructed wetland systems.

The flow to the CWS cells was regulated by a series of concrete v-notch weirs, one for the influent and one for the effluent of each cell. The effluent weir controlled the flow and the hydraulic residence time of the mine drainage through both CWS cells. Each cell was designed for a flow of 7 gpm with a total flow capacity for the two cells of 14 gpm. The remaining flow from the Burleigh Tunnel drainage was diverted to Clear Creek (untreated) via the influent weir. A drainage collection structure was constructed within the Burleigh Tunnel to build sufficient hydraulic head to drive the flow through the two CWS.

1.3.3 Key Features of the CWS Technology

Certain features of the CWS technology allow it to be adapted to a variety of settings:

- The hardware components (geosynthetic materials, PVC piping, and flow control units) of the CWS are readily available.
- Compost materials can be composed of readily available materials. However, the actual composition of a substrate material for a site-specific constructed wetland is best determined through pilot studies. Composted manure was used during this study.
- Operation and maintenance costs are low since the systems are generally self-contained, requiring only periodic changes of the compost depending on site-specific conditions.

Other features that should be thoroughly evaluated before constructing a CWS include the following:

- Properties of the drainage to be treated. Some drainages may need some type of pretreatment before entering the CWS. For example, drainage with high iron or aluminum content might prematurely clog the CWS if not pretreated to remove some of the metal.
- Climate conditions must be evaluated to assess the potential for reduced efficiency of the system during different seasons of the year.
- Contingencies if the system does not perform as expected.

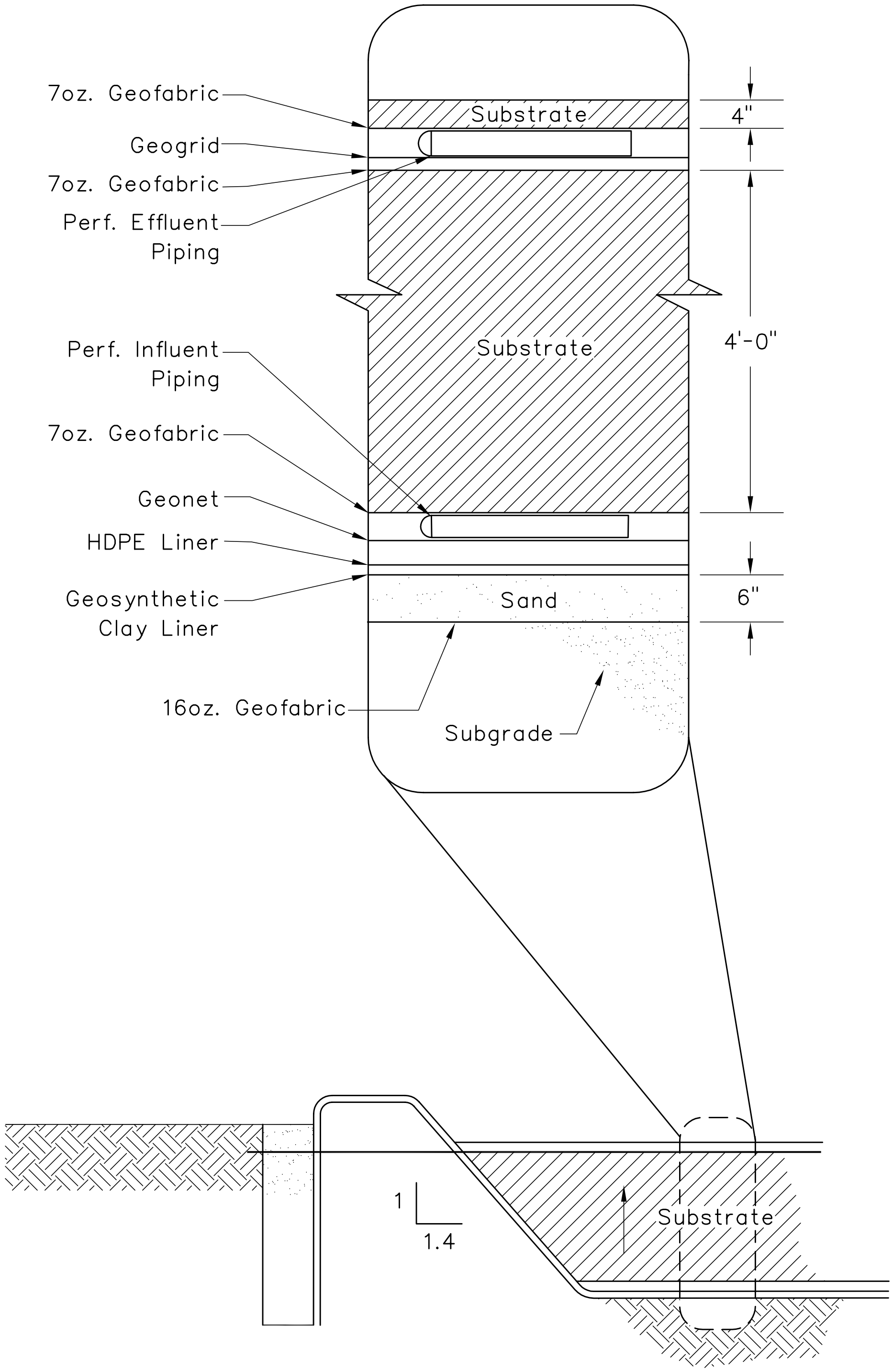

Figure 2. Schematic cross-section of an anaerobic CWS upflow cell.

- Proximity to a populated area—odors generally are associated with CWS treatment.

- Land availability near the source of the contaminated water to avoid extended transport. The CWS typically requires more land than a conventional treatment system. Consequently, locations with steep slopes and drainages would make construction more difficult and costly.

- Cost of constructing the system if substrate and other materials are not readily available.

- Possible use of concrete basins to eliminate replacement costs for liners.

- Potential for vandalism of the CWS, which could result in increased costs.

- Seasonal fluctuation of water flow or chemistry and the potential impact to the CWS.

- Production and release of nutrients from substrate and stream standard requirements for discharge of produced nutrients

1.4 Key Contacts

Additional information on the CWS technology, the SITE program, and the demonstration site can be obtained from the following sources:

The CWS Technology

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